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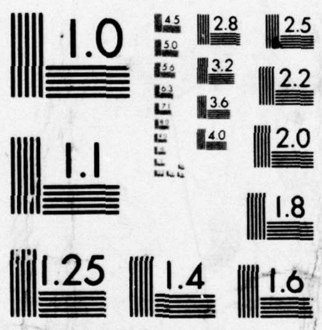

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NAVAL INTELLIGENCE SUPPORT CENTER
TRANSLATION DIVISION
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AUTHOR(S): 10 V.I. Lopatnikov ~~V.I.~~

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MEASUREMENTS OF THE ELECTRIC FIELD IN THE OCEAN

[Lopatnikov, V. I., K probleme izmereniy elektricheskogo polya v okeane, Morskiye Gidrofizicheskiye Issledovaniya, No. 4 (63), 1973, pp. 125-131; Russian].

The article discusses the problem of electric field measurement in a moving coordinate system and the possibility of excluding the induction emf due to the ship's drift in the geomagnetic field during measurement of the electric field in the ocean. It is shown that the problem can be solved on the basis of a new principle of electric field measurement using a current fairing. /125*

The common method of measuring an electric field in the seawater medium is based on the elementary relationship between the potential difference measured by two spaced electrodes forming the base, and the projection of the field strength on the direction of the base. The induction electric field due to the motion of the bases in the geomagnetic field and the electric field determining the current in the medium are not separated in this case. The resulting technical difficulties constitute the chief problem in marine measurements of the electric field, since the latter are made by means of moving measuring systems. The difficulty of solving this problem is just as fundamental as the fundamental relationship between the electric field and the coordinate system in which it is measured. We will indicate some examples. In measuring the electrotelluric field in a deep ocean, when the measuring system is supported on the water surface and the motions of the support are transmitted to the bases, a short-period emf whose magnitude depends on the sea state is induced in the measuring circuit. Since the support is subjected to wind drift and to an emf related to the sea state, there is added a slowly changing /126
emf caused by the nonuniform drift of the system. In determining the vertical structure of the current velocity field with dropping-type EMIT instruments, the induction emf due to the vertical displacement of the base is not excluded from the measuring circuit. Moreover, the intrinsic electrode emf, like the measured emf, may increase in proportion to the size of the base, owing to the difference in physicochemical conditions at different points of the medium. This creates an additional difficulty.

We will attempt to examine this problem by using an expression for the electromagnetic quantities in moving coordinate systems. If in a system at rest relative to the seawater medium under consideration, the electric and magnetic fields are denoted by E and B, the corresponding fields E' and B' in a system moving at velocity v relative to the first system are obtained by means of Lorentz transformations. The components parallel to v remain unchanged, and those perpendicular to v are transformed as follows:

$$E' = \frac{E + vB}{\sqrt{1-\frac{v^2}{c^2}}}, \qquad B' = \frac{B - \frac{v}{c^2}E}{\sqrt{1-\frac{v^2}{c^2}}}.$$

*Numbers in the right margin indicate pagination in the original text.

Since the velocities of the motions considered are always small in comparison with the velocity of electromagnetic waves in a vacuum, the formulas simplify to

$$E = E + vB\,, \quad B = B\,. \qquad (1)$$

These formulas are usually interpreted as an expression for the fundamental relativity of the electric field in the case of slow motions as well. On the contrary, the magnetic field has the property of invariance. Hence, measurements of the magnetic field of currents in the seawater medium by means of an annular magnetic modulator enclosing a definite current tube may be the solution to the problems in question. However, the representativeness of the method is not automatically assured in this case. In the actual construction of the modulator, the ring opening has a finite height, and the phenomena of wave stagnation together with eddy formation in the opening may lead to the existence of some small base with unstable geomagnetic parameters. In this case, the modulator functions as a magnetic amplifier of the voltage induced on the edges of the liquid mass entrained by the ring, and the motions of the modulator generate the noise discussed above. It should be added that annular modulators are exposed to the influence of extraneous magnetic fields, and their actual sensitivity at the present time is insufficient for direct application to the conditions prevailing in the sea. /127

The invariance of the magnetic field and of the electrodynamic laws themselves results in the invariance of the current density. Thus, not only the magnetic recording of the current but also the use of any other current systems should lead to measurement results independent of the motion of the measuring system. However, not any current system is representative. For example, a system with a base conductor under short-circuit conditions is a current system, since the current in the conductor is determined by the electric field strength and conductivity of the medium. For many reasons, such a system will be imperfect and nonrepresentative, owing to the influence of the induction electric field.

Returning to the electric field transformation formula (1), we will examine the validity of the statement concerning the fundamental impossibility of determining the electric field strength, observed in the coordinate system fixed in the medium, by means of an electric field measuring system whose motion is not defined, a statement apparently following logically from the aforementioned relativistic interpretation of the formula. This statement is incorrect when applied to macroscopic phenomena in material media. Measuring systems can be created in which the stated problem is solved, for example, on the basis of the difference between the macroscopic constants of the media in motion. A similar system in which use is made of the difference in the conductivity constants is discussed below. Thus, the formalism of transformation of the coordinates does not provide the key to the solution of the problems under consideration. The problem is to select a representative measuring system excluding the influence of the electric field of the induction due to the motion of the system in a magnetic field, whether the current system is due to a magnetic or electric field.

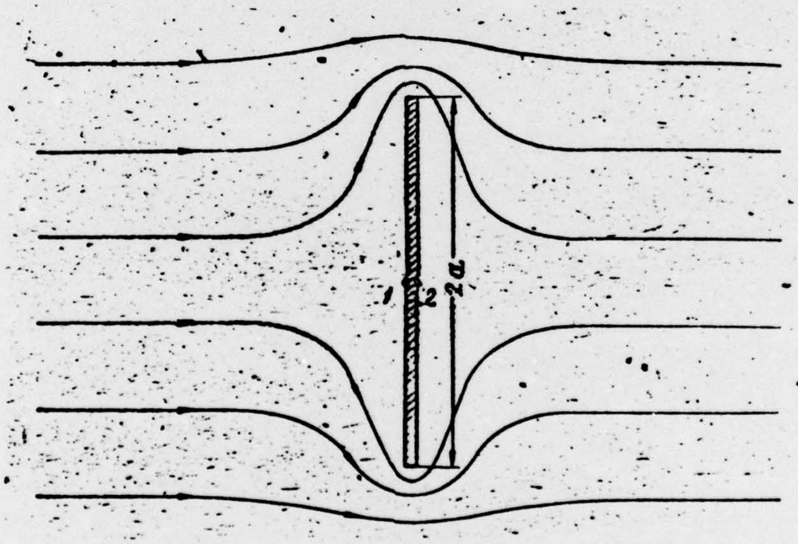
It will be shown that the influence of the induction electric field can be eliminated in measuring systems based on the flow of electric current around nonconducting obstacles.[1] We will consider the field of flow of the current around some sections of nonconducting surfaces in the steady state. In this case, the electric field has a potential, and one can therefore use known solutions of the Laplace equation which describe the field of flow around sections of simplest shapes.

Let the nonconducting surface be represented by a flat, infinitely long strip 2a, whose cross section is shown in the figure. We will give the expres- /128
sion for the complex potential of flow around the strip, which is perpendicular to the direction of the homogeneous electric field, in an elliptical coordinate system[2]

$$w = \varphi - i\psi = aE\,ch\left(\zeta - i\frac{\pi}{2}\right),\quad \zeta = \xi + i\eta,\quad z = x - iy = a\,ch\,\zeta,$$

where x and y are Cartesian coordinates, the direction of the y axis being perpendicular to the plane of the strip; ξ and η being elliptical coordinates, and E, the strength of the undisturbed electric field. The geometry of the current field in the region of the strip is shown in the figure by lines with arrows. According to the condition of flow on the surface itself, the stream function ϕ becomes zero. Therefore, in this case $\xi = 0$, and the potential

$$w = \phi = aE\cos(\eta - \frac{\pi}{2}).$$



Figure

In going from the center of one side of the strip to the center of the other, η changes from $-\frac{\pi}{2}$ to $\frac{\pi}{2}$. The potential difference is

$$\Delta\phi_{1,2} = aE + aE = 2aE. \qquad (2)$$

As a result of the flow effect, on both sides of the strip there is formed an electric potential difference that can be recorded with electrodes attached to the strip. To within the strip thickness, the electrodes here coincide and do not form a base. When such a system is in motion, the excitation of an induction emf in the /129
measuring circuit is excluded to the same accuracy.* Hence, the result expressed

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*Other electromagnetic effects of the motion of the strip, not related to the potentials of the middle points 1 and 2, are neglected here.

in (2) makes it possible to regard the system under consideration as an electric field system that is representative, equivalent, and stationary relative to the medium, with a measuring base equal to the strip width. To elucidate the question of practical applicability of the measurement principle under consideration, we will determine the size of the equivalent base for a system with a limited portion of the plane in the shape of a circle of radius a. When the plane of the circle is perpendicular to the direction of the undisturbed field, the effective potential describing the flow field is[2]

$$\phi = aE[\frac{2}{\pi} (1 - \sinh\xi \operatorname{arcotan} \sinh\xi) \cos\eta + \sinh\xi \cos\eta],$$

where ξ and η are spheroidal coordinates; E is the strength of the undisturbed field. On both sides of the circle $\xi = 0$, and on the surface itself

$$\phi = \frac{2}{\pi} aE\cos\eta.$$

In going from the center of the circle on one side to the center on the other, η changes from 0 to π in this coordinate system. Therefore

$$\Delta\phi_{1,2} = \frac{2}{\pi} aE + \frac{2}{\pi} aE = \frac{4}{\pi} aE.$$

The size of the equivalent base in this case is approximately equal to two thirds of the diameter of the circle.

The above estimates show that the equivalent base corresponding to the flow effect has a size comparable to the dimensions of the portion of the surface in the flow. Since geophysical instruments with bases of 1-3 m are being successfully operated at the present time, and measuring systems with surface portions of the same dimensions are feasible, the measurement principle in question is promising for practical application. Let us note that the combined electrodes are subjected to the same pressure, and the hydrodynamic flow around the surface causes the other physicochemical conditions on both its sides to be the same. Thus, the experimental problems indicated above can be solved completely by using the method under con- /130
sideration.

Without dwelling on narrow technical questions, we will confine ourselves to the following remarks. Obviously, vector measurements can be performed by using mutually perpendicular portions of the plane. The sailing capacity of the system in this case will require the use of a support with freedom of drift. When the support is located on a ship, the system may be combined with a portion of the plane with the base conductor, which like the plane is parallel to the flow. Combination with the transverse conductor makes it possible to use compensation circuits and devices for determining the velocity. For EMIT instruments which drop while rotating, a surface portion in the shape of a right helicoid may be used.

Let us make another general remark. If the portion of the surface in the flow has an opening, the current density in the region of this opening increases in comparison with its values for the undisturbed field. For example, combining an annular magnetic modulator with a portion of nonconducting plane makes it possible to increase the current through the opening of the ring and raise the sensitivity of the system. The noise mentioned above, due to extraneous magnetic fields and also to the induction of an electric field in the opening of the ring, is thus attenuated in proportion to the amplification coefficient of the current through the opening. The

functional relationship between this coefficient and the geometry of the portion can in some cases also be determined analytically, for example for a circle with a central opening. Obviously, a system with a portion of the surface will in this case be transformed into a current system, as in the case of shorting of the electrodes.

Let us note in conclusion that a methodical problem similar to the one discussed exists in the measurement of electric fields in near space. However, the applicability of the solutions examined in the paper is limited to cases in which the mean free path of electrons in the plasma is much shorter than the structurally acceptable dimensions of the nonconducting surface. Such conditions exist, for example, in the region of the ionosphere.

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2. Milne-Thomson, L. M., Theoretical Hydrodynamics. "Mir" Publishing House, Moscow, 1964.